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Ultra-Wideband Low-Noise Amplifier

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Abstract

Ultra-Wideband (UWB) Low-Noise Amplifier (LNA) is an essential part of the digital TV and UWB signal processor, but what makes it hard to design is the comprehensive consideration of bandwidth, noise and gain control performance. A new solution of high performance amplifier with low-noise, UWB and direct current (DC) is presented (Fig.1), which is composed of a precision pre-amplifier with AD797, a stepped gain controller with VCA810 and a digital potentiometer, an eight-order Bessel low-pass filter with LC network, a zero-drift corrector with the digital compensation method. The test results (Tab 1-3 & Fig.6) show that the gain of amplifier can be adjusted from 0 to 80dB by step, the fluctuation of the pass band from DC to 10MHz is less than 0.87dB, stop-band attenuation reaches -42dB/2f_c, the equivalent input noise voltage is less than 7.2μV_{rms}. This design successfully solves some high challenging contradictions, such as ultra-wideband and low-noise, stop-band attenuation and pass-band fluctuation, precise gain control and DC zero-drift correction.

Keywords :amplifier; ultra-wideband; low-noise; gain control; zero-drift correction

1 Introduction[1]

Ultra-wideband (UWB) Low-Noise Amplifier (LNA) is widely used in the mid-frequency and video amplifiers. This kind of circuit is not only used to amplify the video signal, impulse signal and RF signal with the bandwidth ranging from DC to several MHz or even tens of MHz [1], but also widely applied in the signal processing [2]. In recent years, with the rapid development of ultra-wideband in the covert communication [3] and target detection [4], higher requirements for the bandwidth are claimed by the UWB signal, thus the front-end preprocessing circuit of the receiver must be a low-noise amplifier [5][6] with UWB [7]-[9].

The performance [10] of the ultra-wideband amplifier directly influences the precision of signal detection and processing. As a consequence, the design of low-noise, low zero-drift and ultra-wideband becomes the key point which is of great engineering significance and application value [11]. In other references, the typical gain of UWB LNA was 12-20dB [12] and there was also a contradiction between performance and feasibility. For example, Ref. [13] [14] proposed the amplifier which solved the problem

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of ultra-wideband and low-noise，but it couldn't avoid zero-drift and high NF.

This paper designed and realized a low-noise wideband amplifier made up with the low-noise amplifier, high performance filter network [15], and digital program control circuit for zero-drift correction [16], MCU control system and high precision power supply. Several contradictions such as the ultra-wideband and low-noise, the high stop-band attenuation and low pass-band fluctuation, the high precise gain control and the compensation of DC zero-drift, etc. were successfully solved [17]. The design of our machine got superior parameters and reliable performance together with better promotion value.

2 Solution Of Low-Noise And Ultra-wideband

The functional block diagram of the low-noise wideband DC amplifier is shown in Fig. 1. The amplifier system contains five parts: the primary amplifier, filter network, zero-drift correction circuit, control system and high performance power supply. The primary amplifier consists of low-noise precise pre-amplifier, gain control, mid-amplifier and power driver circuit outputted by the final push-pull. The low-noise precise pre-amplifier adopts the ultra low-noise integrated operational chips, realizing the low-noise for the whole system. Voltage gain is adjusted by the MCU. Mid-amplifier consists of the low-noise, high speed integrated amplifier in order to increase the system gain. Final end power driver adopts the dual op-amp consisting of the pull-push output to increase the loading ability of the system. The high performance filter adopts the passive filter proposal to realize the 0~5MHz and 0~10MHz dual channel, eight-order Bessel low-pass filter with the switchable wave band. The zero-drift correction has two proposals: analog revised and digital revised, and here we adopt the digital one to increase the correction precision. The control system is to realize the gain and zero-drift digital control with the MCU AT89C52 [18] as the centre. Power supply adopts the mixed regulator, through the decoupling filter, secondary regulator and precise regulator in order to provide the precise low-noise DC power for the whole system.

3 Design Of Circuits And Calculation Of Parameters

3.1 The design of low-noise and ultra-wideband

Decreasing the output noise is the key to the wideband amplifier. By using the Friis Formula we can get the noise coefficients of the cascade amplifier [19]:

$$NF = NF_1 + \frac{NF_2 - 1}{K_{pa1}} + \frac{NF_3 - 1}{K_{pa1}K_{pa2}} + \ldots + \frac{NF_n - 1}{K_{pa1}K_{pa2}\ldots K_{pa(n-1)}}$$

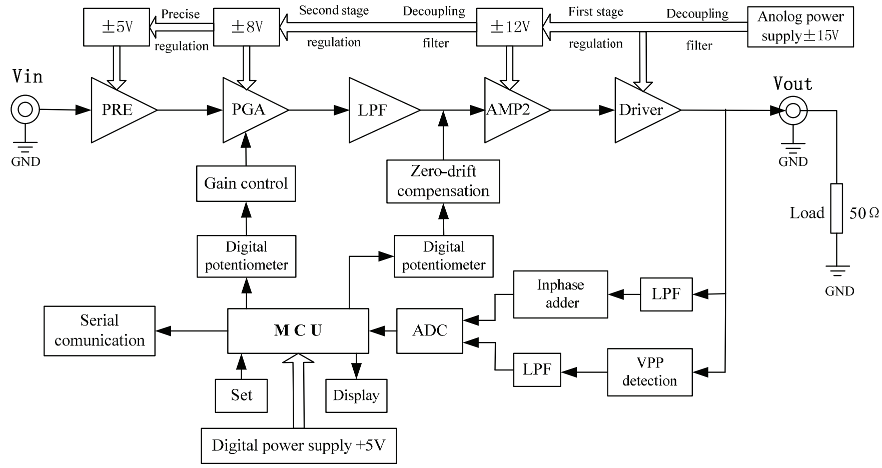

Fig. 1 The ultra-wideband Low-Noise DC amplifier proposal

Where NF_1、$NF_2 \ldots NF_n$ are the noise coefficients of each amplifier, and K_{pa1}、$K_{pa2} \ldots K_{pa(n-1)}$ are the gains of each amplifier. From the Friis Formula we can see what affects the cascade amplifier most is the first stage amplifier, so we should try to get an amplifier of smaller noise coefficient and larger gain in the low-noise design.

The design chooses the ultra low-noise integrated op-amp AD797 as the pre-amplifier matching the appropriate source impedance. The peripheral devices consist of high performance low-noise metal film resistors and each stage adopts low-noise chips. The LC low-pass filter with bands of 0~5MHz and 0~10 MHz is designed. And also the analog and digital grounds are separated in the PCB layout and masking technique is also adopted in the preceding stage in order to decrease the output noise voltage. The low-noise pre-amplifier consisting of AD797 is shown in Fig. 2.

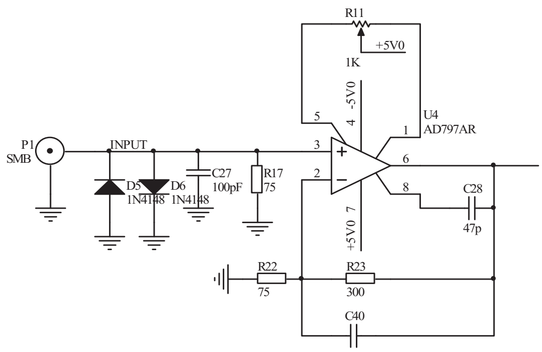

Fig. 2 Ultra low-noise pre-amplifier

3.2 Program gain control

Gain controller is a kind of control method with the amplifier gain changing along with the external control signal. In this system, the program gain control is realized easily by using the external keyboard to set the gain, the voltage gain control amplifier VCA 810 is selected as gain controller.

With the control of MCU, the digital potentiometer X9C103 adjust the output voltage ranging between 0~2V, which is added to the VCA810 gain control pin. In this way, we can reach the system with the gain of 0~80dB and the 1dB step adjustable. The principle circuit of gain controller is shown in Fig. 3.

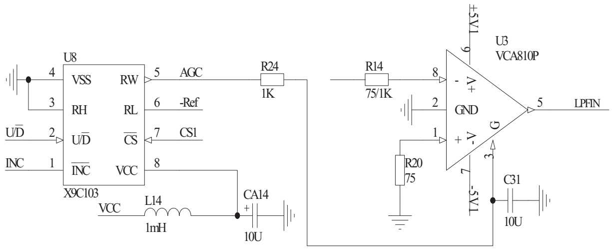

Fig. 3 Principle circuit of gain controller

3.3 DC zero-drift correction

DC zero-drift is that the operating point of DC amplifier irregularly, slowly and gradually changes. The greater the gain and the more magnification series, the more serious the phenomenon will be, even making the op-amp work badly when the zero-drift reaches the saturation. So a DC zero-drift correction circuit must be designed in order to guarantee the stability of DC amplifier. Through A/D sampling, the DC zero-drift detected in the final stage is sent into the MCU, then we can realize the automatic set of zero by choosing the proper reference voltage and using MCU to control digital potentiometer X9C102 with a compensation voltage adding to the zero regulating end. The zero-drift correction circuit is shown in Fig. 4.

3.4 High performance filter network

The filter is mainly used to reduce the noise, filter band interference and improve system stability. In this design, two low-pass filter pass-bands are 0～5MH and 0～10MHz, with the additional requirements of the pass-band fluctuation less than 1 dB, and stop-band attenuation 40dB/2fC, so precise capacitance and inductance are used to achieve the eight-order passive LC low-pass filter. In order to realize the linear phase, the Bessel filter has to be adopted. As for the complicated calculation and hardship in setting the parameters of LC filter, we can use the software named *Filtering Solutions* to do some computer aided design. The high performance filter is shown in Fig. 5.

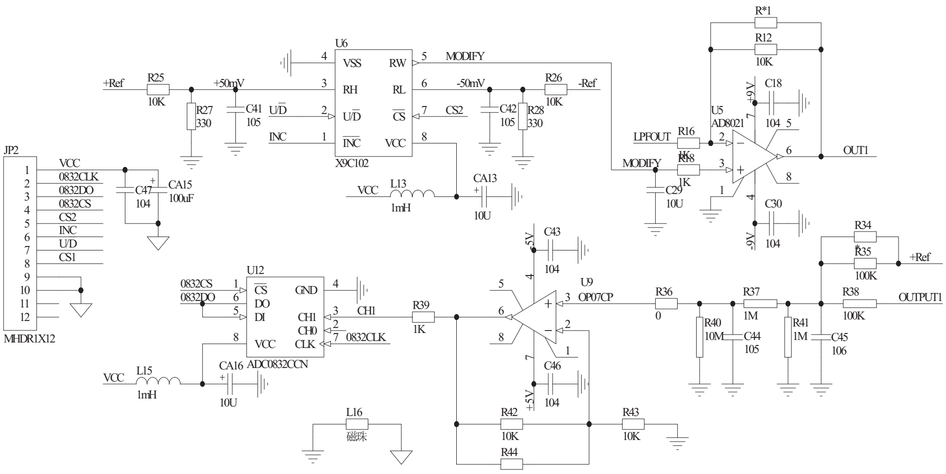

Fig. 4 Zero-drift correction circuit

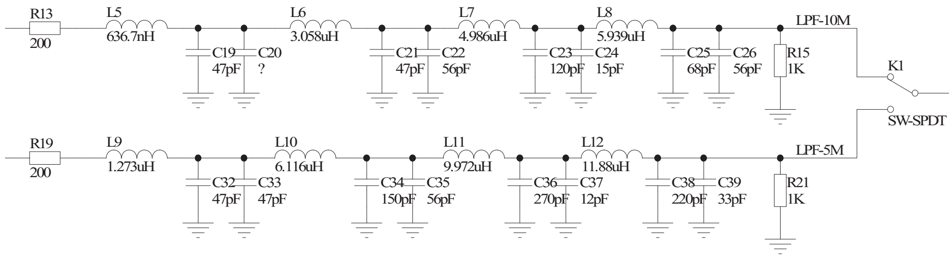

Fig. 5 8-order Bessel low-pass filter

4 System performance test

4.1 *The measurement of the system's self-noise*

The system is plugged in ±15V DC power supply with the input shorted to GND. The amplifier gain was adjusted to Av=40dB、60dB、80dB. The oscilloscope was used to observe the output noise waveforms of each amplifier and the Agilent 34401A was used to measure the RMS of noise voltage, the measure results are shown in TABLE I.

4.2 *The test of zero-drift correction*

Keeping the input shorted and use the MCU to control the digital potentiometer, adding the compensation voltage by a step of 20 dB, adjusting the gain of amplifier in order to suppress the DC zero-drift .Use Agilent 34401A to measure the correction voltage under different magnifications, the results are shown in TABLE II.

4.3 *The calibration of the gain*

Set the working frequency band at 0~10MHz and the input signal frequency f_i = 2MHz. Respectively, set the gain of amplifier separately at 0、20dB、40dB、60dB、80dB and input the appropriate signal amplitude V_i, use dual-channel oscilloscope to observe the input and output, record the output signal amplitude, calculate amplifier real gain and make comparisons with the set, the results are shown in TABLE III.

4.4 *Amplitude-frequency characteristics of the system*

Fix the amplitude of the input signal Vi = 100mV_{pp}, A_V=40dB, adjust the signal frequency between 0～20MHz, then use the oscilloscope to observe V_{PP} of the output signals with different frequency input signals and record them. Draw the curve of amplitude-frequency characteristic with MATLAB [20], which is shown in Fig.6.

TABLE I The Self-Noise Of The System

Working Frequency	0～5MHz		0～10MHz	
Gain A_V (dB)	60	80	60	80
Output Noise U_{on} (mV_{rms})	5.687	60.86	6.236	72.39
Input Noise U_{in} (μV_{rms})	5.7	6.1	6.2	7.2

TABLE II Characteristics Of The Zero-drift Correction

Gain Av (dB)	0	20	40	60	80
Zero-drift voltage before correction (mV)	75.6	22.0	-21.0	24.8	-65.8
Zero-drift voltage after correction (mV)	1.2	2.5	-4.6	2.6	2.9

TABLE III Test Of The Correction Gain

A_{V0} (dB)	0	20	40	60	80
V_i (mV_{pp})	200	200	100	10	1
V_o (V_{pp})	0.20	2.05	10.5	10.5	10.2
A_{VR} (dB)	0	20.214	40.424	60.424	80.172
$\triangle A_V$ (dB)	0	0.214	0.424	0.424	0.172

Note: A_{V0} is the set gain, A_{VR} is the real gain, $\triangle A_V$ is the gain error, $\triangle A_V = A_{VR} - A_{V0}$

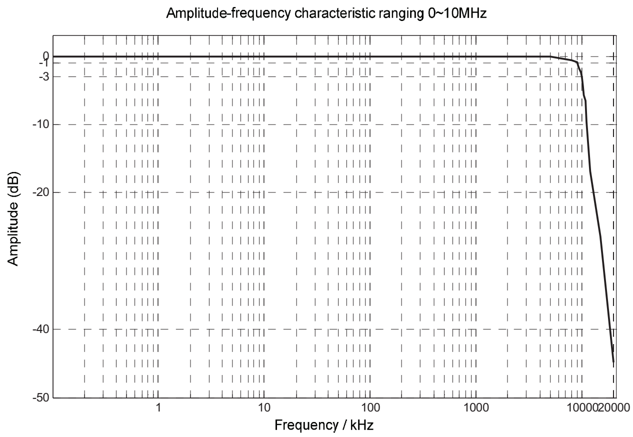

Fig.6 Amplitude-frequency characteristics of the system

5 Conclusion

In this paper, the key technology of the ultra-wideband low-noise DC amplifier was researched. A high performance amplifier based on ultra-low-noise pre-amplifier, LC filter network, digital program gain control and zero-drift correction circuit was presented. The D/A converter was adopted to control the low-noise wideband amplifier VCA810, and the dynamic voltage gain range 0~80dB was achieved, the linear phase low-noise filter with band 0~10MHz was realized with the passive wideband Bessel low-pass filter, which composed by the inductance and capacitance, matched up with the low-noise preamplifier AD797, the equivalent input noise less than 7.2 μV_{rms} was guaranteed. The MCU was used to control the digital potentiometer X9C102 to add compensation voltage to the zero-set end in order to realize the auto-adjustment of DC zero-drift. The test results show that the amplifier designed works with low-noise, small offset, high cost-effective, great stability and reliability.

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